ELECTRICITY MARKETS & POLICY

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Variable Renewable Energy Participation in U.S. Ancillary Services Markets: Economic Evaluation and Key Issues

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Introduction

- Rising penetrations of variable renewable energy (VRE) are reducing VRE energy and capacity value in organized markets; VRE owners are looking for other sources of value
- Rising VRE penetrations are also creating new challenges for system operations; system operators will need to explore low-cost integration solutions
- Enabling VRE participation in AS markets could provide additional revenue sources and allow system operators to access lower-cost integration solutions

Main study questions:

1) What is the additional value ($/MWh) of AS market participation to standalone and hybrid* VRE resource owners?

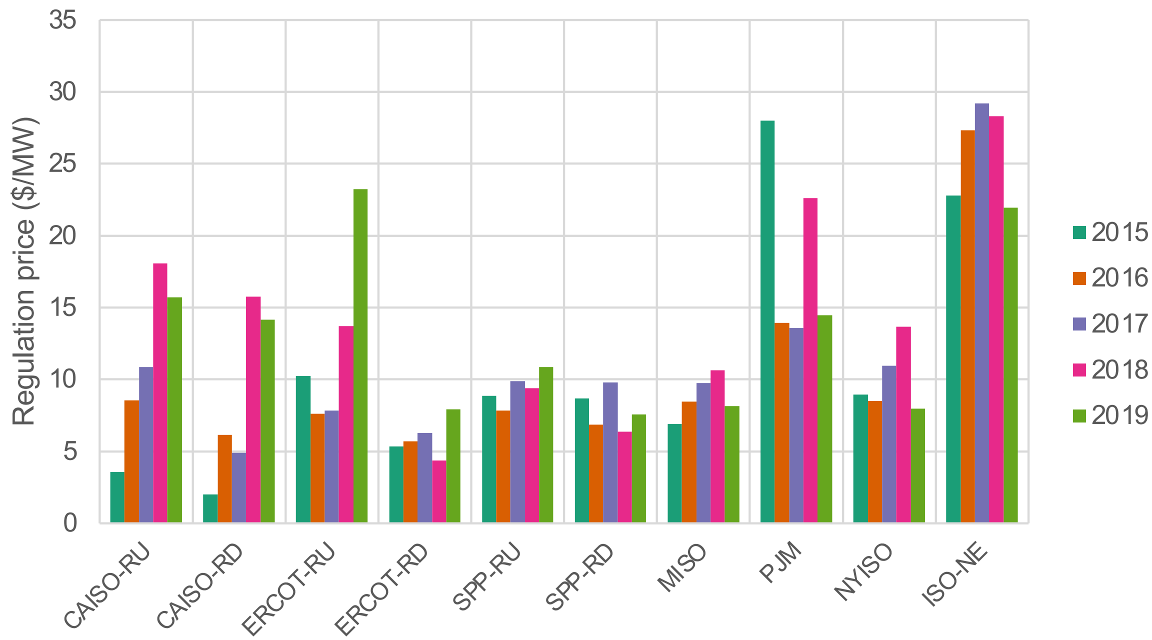
2) Can VRE provide high value reserves to the electricity system?

** Hybrid refers to VRE with co-located storage*

Background: ISO/RTO AS markets

- ISO/RTO AS markets have significantly different products, procurement practices, and price formation
  - Design differences have significant impact on AS prices, price structure, and value
- AS prices vary significantly year to year
  - Price variance driven by fuel costs, loads, hydro variability, market design changes

Simple average zonal regulation prices used in this analysis by ISO/RTO, 2015-2019



Notes: RU refers to regulation up, RD refers to regulation down
Source: Prices are from Velocity Suite

Background: ISO/RTO AS markets

- Three differences in ISO/RTO AS market design that are most relevant for this analysis:
  - **Products**: separate regulation up/down (CAISO, ERCOT, SPP) or bidirectional regulation (ISO-NE, MISO, NYISO, PJM)
  - **Co-optimization**: day-ahead and real-time co-optimization (CAISO, MISO, NYISO, SPP), real-time co-optimization (ISO-NE, PJM), day-ahead co-optimization (ERCOT); differences in which reserves are co-optimized
  - **Price cascading**: regulation ≥ spinning ≥ non-spinning/supplemental (CAISO, MISO, NYISO, SPP) or spinning ≥ non-spinning (ERCOT, ISO-NE, PJM)
- For overviews of ISO/RTO AS markets, see Ellison et al. (2012), Zhou et al. (2016), and Ela et al. (2019)

Background: VRE participation in AS markets

- Standalone VRE's ability to provide essential reliability services has been extensively demonstrated (Kirby and Milligan, 2009; Ela et al., 2014; Milligan et al., 2015; Loutan et al., 2017; Loutan et al., 2020; Rebello et al., 2020) but limited to no participation in U.S. AS markets to date
- ISOs/RTOs beginning to address hybrid VRE participation models after FERC Order 841; Hybrid VRE will be able to provide AS under CAISO's hybrid participation model in 2021
- Standalone and hybrid VRE participation in AS markets would have different operations and economics

Background: Standalone VRE participation

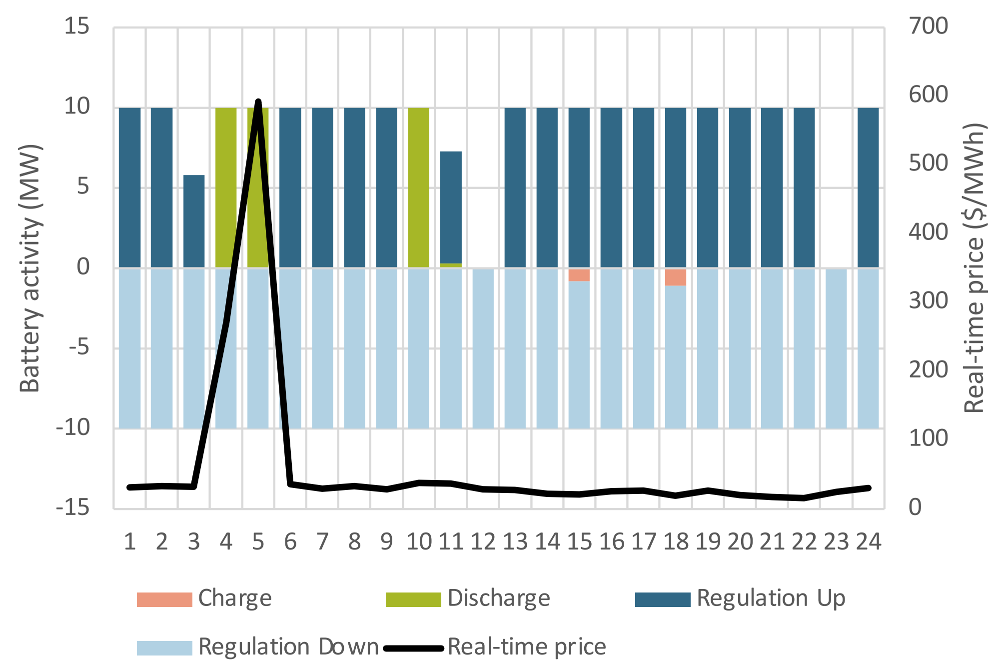
- Standalone VRE provision of different reserves/products would have different operating requirements and economic principles

	Upward reserve (regulation up, spinning)	Downward reserve (regulation down)	Bidirectional regulation
Day-ahead market operations	Reduction in day-ahead forecasted output (financial) during scheduling interval	No changes to day-ahead forecasted output	Reduction in day-ahead forecasted output (financial) during scheduling interval
Real-time market operations	Curtailment of 5-minute forecast in target dispatch interval	No curtailment of 5-minute forecast	Curtailment of 5-minute forecast in target dispatch interval
Reserve dispatch	Upward regulation energy and contingency dispatch	Curtailment (downward regulation)	Upward/downward regulation energy
Opportunity cost	Cost of not providing energy (LMP), minus any revenues from reserve dispatch	Cost of not providing energy (LMP) when curtailed for regulation energy	Cost of not providing energy (LMP)
Energy versus reserve provision	Provide reserves if reserve price + energy revenues > energy price	Provide reserves if reserve price > lost revenues from regulation down energy	Provide reserves if reserve price > energy price

Background: Hybrid VRE participation

- In hybrid VRE, storage will dominate reserve provision
- Batteries tend to maintain state of charge (SOC) sufficient to provide downward regulation at max charge rate and then provide upward regulation, unless (a) energy price differences are high enough to offset lost regulation revenues during time between energy charge and discharge or (b) regulation prices are low

Illustration of battery dispatch on a day with an energy price spike



- Point of interconnection (POI) capacity limits may limit total output from VRE + storage facility
  - POI capacity may be less than nameplate VRE capacity + storage discharge capacity

Analysis methods

- 20 MW wind and solar facilities (standalone and hybrid), 10 MW/40 MWh battery storage (hybrid)
- Profit maximizing dispatch against 2015-2019 ISO/RTO energy and reserve prices
  - Real-time energy, regulation, and spin prices in all markets except for ERCOT; day-ahead prices in ERCOT
  - Perfect foresight assumption
- Base case only includes regulation reserves
  - Regulation up/down (CAISO, ERCOT, SPP), bidirectional regulation (ISO-NE, MISO, NYISO, PJM)
  - Spinning reserve provision considered as a sensitivity

Metrics

Resource owner perspective

$$\Delta r = \frac{NE_1 + AS_1 - NE_0}{G_{PC}}$$

System perspective

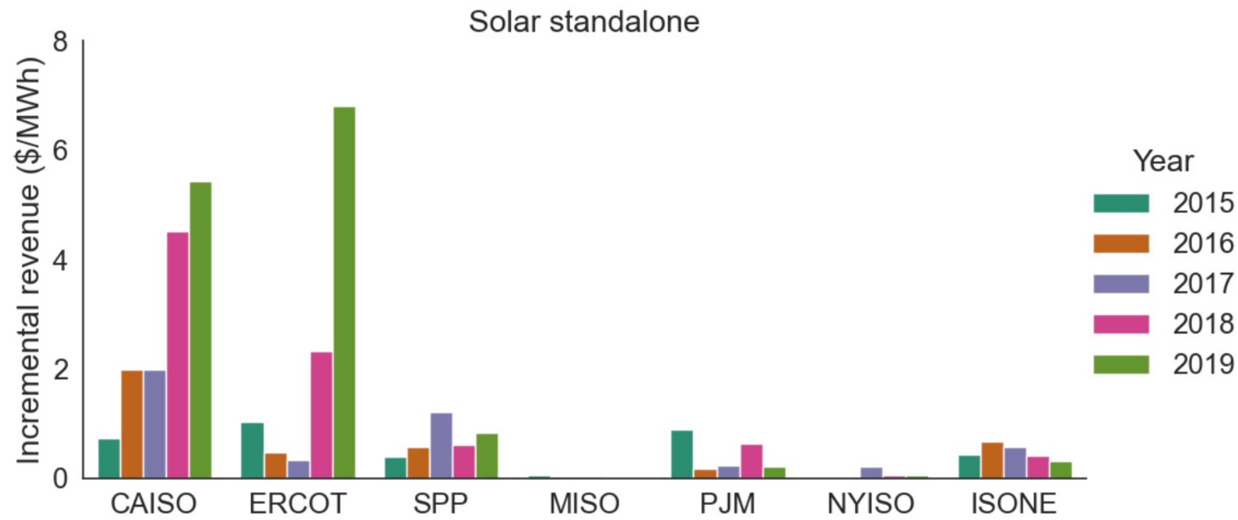
$$v = \frac{AS_1}{RS_1}$$

r = unit revenue, pre-curtailment MWh ($/MWh$_{PC}$)
NE = net energy revenue ($/yr)
AS = reserve revenue ($/yr)
G_{PC} = pre-curtailment VRE generation (MWh$_{PC}$/yr)
v = unit AS value ($/MW-h)
RS = AS provision (MW-h/yr)
Subscript 1 = with AS case
Subscript 0 = without AS case
Subscript PC = pre-curtailment

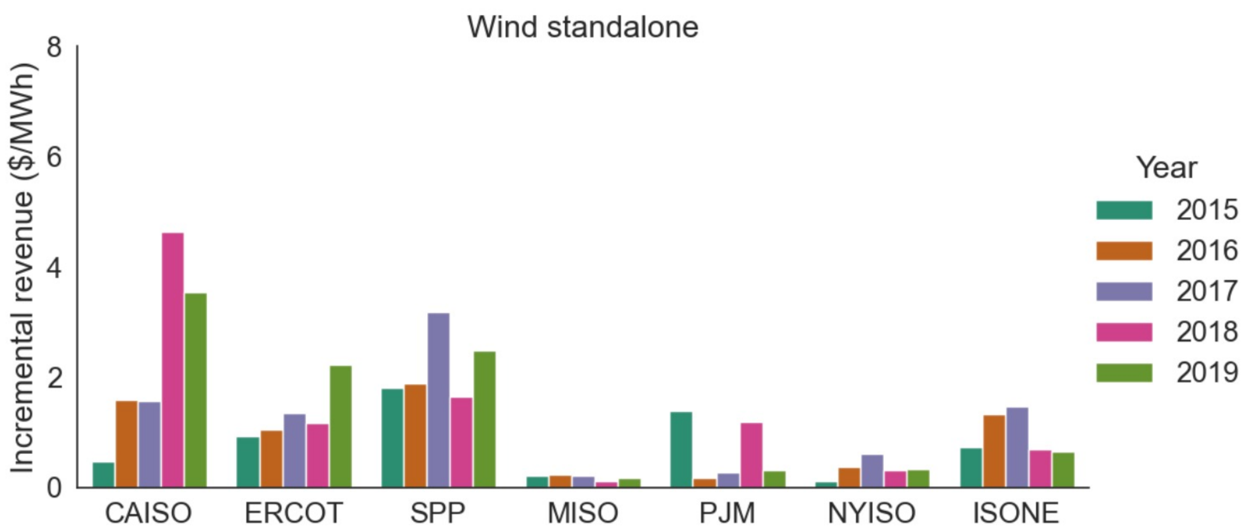
Analysis methods

- Other key assumptions:
  - Zonal AS prices, chosen using "central plant" search algorithm
  - POI capacity limited to 20 MW (VRE facility nameplate capacity), maximum POI capacity of 30 MW (VRE + battery capacity) considered as a sensitivity
  - For hybrid VRE, only battery can provide reserves (assuming storage reserve value >> VRE reserve value)
  - Regulation reserves provide energy (up/down) equivalent to 30% of regulation award, spinning reserves provide contingency dispatch energy equivalent to 2% of spinning award
  - Deterministic hourly resource profile for wind and solar, perfect foresight for battery dispatch
  - For standalone VRE, wind and solar can provide reserves equivalent to 20% of hourly profile, minimum of 1 MW
  - Different battery degradation rates for energy ($5/MWh) and reserves ($25/MWh for dispatched energy)
  - Battery SOC not limited by contractual requirements (e.g., RA requirements)
  - Analysis does not consider mileage value (expected to be low relative to AS capacity value and opportunity cost)

Results: Incremental value for standalone VRE owner



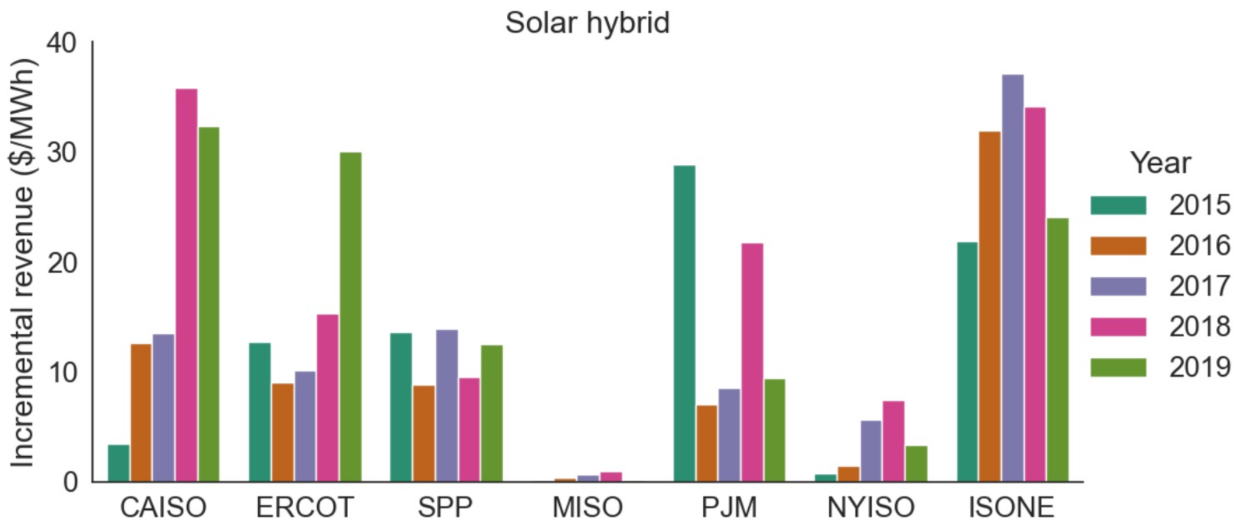
Averages (%Δ)	$2.9/MWh (10%)	$2.2/MWh (6%)	$0.7/MWh (3%)	$0.0/MWh (0%)	$0.4/MWh (1%)	$0.1/MWh (0%)	$0.5/MWh (1%)



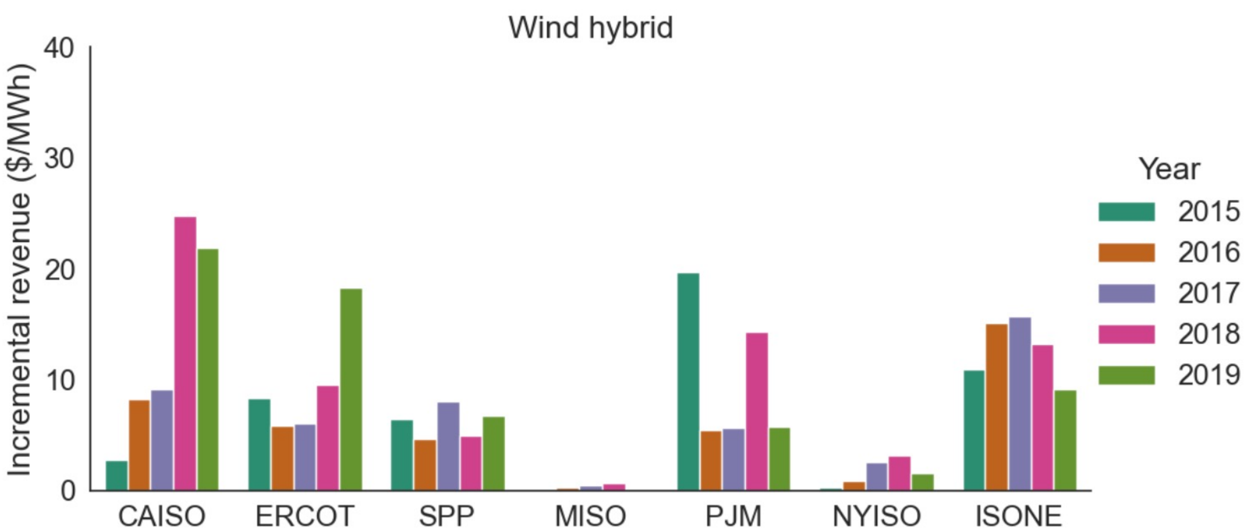
Averages (%Δ)	$2.4/MWh (7%)	$1.3/MWh (7%)	$2.2/MWh (15%)	$0.2/MWh (1%)	$0.7/MWh (2%)	$0.4/MWh (1%)	$1.0/MWh (3%)

- Incremental value varies significantly across ISOs/RTOs, years, between solar and wind
- Differences in value among ISOs/RTOs due in part to market design
  - Separate regulation up/down versus bidirectional regulation
- Inter-annual value differences within ISOs/RTOs driven by prices and energy-regulation price relationship
- Differences in solar versus wind driven by differences in resource profiles, market prices, and capacity factors

Results: Incremental value for hybrid VRE owner



Averages (%Δ)	$20/MWh (47%)	$15/MWh (37%)	$12/MWh (34%)	$0.5/MWh (1%)	$15/MWh (33%)	$4/MWh (8%)	$30/MWh (62%)



Averages (%Δ)	$13/MWh (33%)	$10/MWh (38%)	$6/MWh (32%)	$0.3MWh (1%)	$10/MWh (31%)	$2/MWh (6%)	$13/MWh (31%)

- Average incremental value much higher than hybrids than for standalone
- Differences in value among ISOs/RTOs and years mainly driven by differences in market design and regulation price levels
- Differences in solar versus wind driven by differences in profiles, capacity factors, and timing of POI capacity constraints

Results: Electricity system value

Regulation provision and regulation value, 2018 market prices

		Regulation provision (average MW), % capacity in parentheses				Regulation value and ISO average regulation price ($/MW)				
		Standalone		Hybrid		Standalone		Hybrid		ISO AVG
		Solar	Wind	Solar	Wind	Solar	Wind	Solar	Wind	
CAISO	**RD**	0.95 (5%)	0.91 (5%)	4.37 (44%)	4.23 (42%)	$26	$31	$31	$32	$12
	RU	0.42 (2%)	0.47 (2%)	3.92 (39%)	3.54 (35%)	$37	$62	$38	$40	$14
	Total	1.37 (7%)	1.38 (7%)	8.29 (83%)	7.78 (78%)	$29	$42	$34	$36	
ERCOT	**RD**	0.18 (1%)	0.82 (4%)	1.49 (15%)	1.45 (14%)	$8	$11	$14	$15	$4
	RU	0.24 (1%)	0.54 (3%)	3.09 (31%)	3.10 (31%)	$78	$16	$32	$32	$14
	Total	0.42 (2%)	1.36 (7%)	4.58 (46%)	4.55 (45%)	$48	$13	$26	$27	
SPP	**RD**	0.28 (1%)	1.32 (7%)	2.73 (27%)	2.42 (24%)	$12	$13	$15	$16	$9
	RU	0.15 (1%)	0.70 (3%)	2.43 (24%)	2.20 (22%)	$34	$14	$22	$23	$6
	Total	0.43 (2%)	2.02 (10%)	5.16 (52%)	4.63 (46%)	$19	$13	$18	$19	
MISO		0.03 (0%)	0.28 (1%)	1.22 (12%)	1.33 (13%)	$7	$6	$12	$12	$11
PJM		0.11 (1%)	0.27 (1%)	6.15 (62%)	6.00 (60%)	$67	$64	$26	$27	$23
NYISO		0.04 (0%)	0.38 (2%)	3.79 (38%)	3.05 (30%)	$10	$11	$15	$15	$14
ISO-NE		0.16 (1%)	0.51 (3%)	10.19 (102%)	8.26 (83%)	$34	$32	$21	$21	$28

- Regulation provision in bidirectional regulation markets tends to be low
- Wind provides more regulation than solar but solar value is often higher
- Hybrid value is often, but not always, higher than standalone value
- Standalone/hybrid value is often, but not always, higher than ISO average regulation price

RD is downward regulation; RU is upward regulation; Total is combined RD and RU

For hybrids, capacity is the nameplate capacity of the battery (10 MW)

Sensitivities

- The analysis considers four sensitivities:
  - Max POI – increase POI capacity from 20 MW to 30 MW for hybrids
  - Reg + spin – resources can provide spinning reserve in addition to energy and regulation reserve
  - Spin – resources can only provide energy and spinning reserve
  - High VRE penetration – compare results in high versus low VRE scenarios, using 2030 price forecasts
- Max POI, reg + spin, and spin sensitivities all use 2018 energy and AS market prices
- High VRE penetration sensitivity uses 2030 LCG price forecasts from *Impacts of High Variable Renewable Energy Futures on Wholesale Electricity Prices, and on Electric-Sector Decision Making* study
  - Low VRE versus High VRE scenarios (balanced wind/solar, consistent capacity balancing)

Sensitivities: Spinning reserves and POI limits

Incremental value to VRE owner, 2018 market prices

	CAISO	ERCOT	SPP	MISO	PJM	NYISO	ISO-NE
Standalone solar							
Base case	$4.6	$2.3	$0.6	$0.0	$0.6	$0.1	$0.4
Energy + reg + spin	$4.9	$3.0	$0.6	$0.0	$0.6	$0.1	$0.4
Energy + spin	$0.3	$0.8	$0.0	$0.0	$0.0	$0.0	$0.0
Standalone wind							
Base case	$4.7	$1.2	$1.7	$0.1	$1.2	$0.3	$0.7
Energy + reg + spin	$5.2	$1.5	$1.7	$0.1	$1.2	$0.3	$0.7
Energy + spin	$0.5	$0.3	$0.0	$0.0	$0.0	$0.0	$0.0
Hybrid solar							
Base case	$36.7	$16.1	$10.2	$1.7	$23.6	$9.4	$37.1
Max POI	$37.9	$18.2	$11.5	$2.3	$26.7	$10.1	$40.7
Energy + reg + spin	$36.7	$17.8	$10.5	$2.1	$23.5	$9.4	$37.0
Energy + spin	$2.8	$8.3	$0.9	$0.8	$0.8	$0.8	$0.7
Hybrid wind							
Base case	$25.4	$10.1	$5.3	$1.1	$15.3	$4.0	$14.4
Max POI	$27.3	$11.0	$6.3	$1.4	$17.8	$5.1	$20.0
Energy + reg + spin	$25.4	$10.9	$5.4	$1.3	$15.2	$3.9	$14.4
Energy + spin	$1.9	$5.2	$0.4	$0.5	$0.4	$0.2	$0.3

Note: Base case is energy + reg with a 20 MW POI limit.

- POI limit increase has limited impact on hybrid results
- Spinning reserves provide low to no incremental value for standalone VRE
  - Result of price cascading and low spin prices
- Spinning reserves provide higher incremental value for hybrids, but still low relative to regulation

Sensitivities: Higher VRE penetration (2030)

Incremental value to VRE owner, 2030 price forecast

	CAISO	ERCOT	SPP	NYISO
Standalone solar				
High VRE	$1.4	$6.6	$14.8	$2.0
Low VRE	$0.0	$0.1	$0.0	$0.0
Standalone wind				
High VRE	$1.3	$2.7	$6.6	$1.4
Low VRE	$0.0	$0.5	$0.3	$0.0
Hybrid solar				
High VRE	$34.3	$40.8	$64.1	$20.6
Low VRE	$5.4	$25.2	$7.1	$0.9
Hybrid wind				
High VRE	$21.6	$22.3	$35.9	$10.0
Low VRE	$3.2	$12.0	$3.4	$0.6

Low VRE – “Low VRE” scenario, wind and solar shares frozen at 2016 levels
High VRE – “Balanced VRE” scenario (20% wind, 20% solar)

- Higher VRE penetration may significantly increase value of VRE AS provision
  - Increase in regulation prices, changes in energy-regulation price relationship
- LCG price forecasts do not incorporate higher penetrations of storage, would reduce incremental values for standalone and hybrids

Key issues

Results are sensitive to:

- **AS market participation barriers** – *will standalone VRE be able to participate in AS markets, and what other barriers might exist to AS market participation?*
- **Future AS market volumes and pricing** – *how would higher VRE penetration and VRE and storage participation in AS markets affect the results?*
- **Other or new sources of value** – *what other revenue sources might AS market participation provide, and will new AS products provide additional opportunities for VRE?*

AS markets tend to be relatively thin; energy storage currently in interconnection queues could saturate AS markets

ISO/RTO	Regulation Reserve Requirement (% Peak Demand)	Spinning Reserve Requirement (% Peak Demand)	Energy Storage in Interconnection Queue	
			Standalone Storage	Hybrid Storage
CAISO	RU: 320 MW (0.6%) RD: 360 MW (0.7%)	800 MW (1.6%)	22,712 MW	37,339 MW
ERCOT	RU: 318 MW (0.5%) RD: 295 MW (0.4%)	2,617 MW (3.8%)	12,779 MW	7,638 MW
SPP	RU: 470 MW (0.9%) RD: 325 MW (0.6%)	585 MW (1.1%)	5,734 MW	3,579 MW
MISO	425 MW (0.4%)	740 MW (0.6%)	2,536 MW	2,674 MW
PJM	Off-p: 525 MW (0.4%) On-p: 800 MW (0.6%)	1,505 MW (1.0%)	14,898 MW	8,046 MW
NYISO	217 MW (0.7%)	655 MW (2.2%)	11,889 MW	268 MW
ISO-NE	60 MW (0.3%)	900 MW (3.8%)	3,645 MW	237 MW
Total	4,817 MW	7,802 MW	74,193 MW	59,781 MW

Sources: Regulation and spinning reserve requirements are from Denholm et al. (2019); interconnection queue data are based on data from Rand et al. (2021).

Conclusions

- Incremental value of VRE AS market participation to resource owners varies by resource type (standalone/hybrid, solar/wind) and across ISO/RTO markets
  - Average incremental value of regulation market participation to standalone VRE owners can be non-trivial in markets with separate regulation up/down products; incremental value to hybrid VRE owners is high in most markets
  - Incremental value to resource owners would likely increase with higher VRE penetrations
  - However, thinness of AS markets means that incremental value would likely decline with expanded AS market participation
- Standalone and hybrid VRE can provide regulation reserves in high priced hours, implies that there may be high system value of expanding AS market eligibility to enable lower-cost reserve solutions
- Results provide insights around strategies to enable VRE participation in AS markets
  - Separate upward/downward regulation products could create more value for resource owners and the system as a whole
  - First step may be to enable hybrid VRE participation, but ultimately may be beneficial to enable both hybrid and standalone participation

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